

Contents

Part I Bioinformatics

1 Modeling Macromolecular Complexes: A Journey Across Scales	3
Frédéric Cazals, Tom Dreyfus, and Charles H. Robert	
1.1 Introduction	3
1.1.1 Structure of Macromolecular Systems	4
1.1.2 Dynamics of Macromolecular Systems	6
1.1.3 Simulation, Geometry, and Insight	7
1.1.4 Chapter Overview	8
1.2 Modeling Atomic Resolution Complexes	10
1.2.1 Challenges	10
1.2.2 Affine Voronoï Diagrams and α -Shapes	15
1.2.3 Molecular Surfaces and Volumes	19
1.2.4 Modeling Interfaces	20
1.2.5 On the Morphology of Binding Patches and Interfaces	22
1.2.6 Success Stories	23
1.3 Modeling Large Assemblies	25
1.3.1 Challenges	26
1.3.2 Toleranced Models and Curved Voronoï Diagrams	29
1.3.3 Stability Analysis of Multi-scale Toleranced Models	32
1.3.4 Building a Toleranced Model from Probability Density Maps	34
1.3.5 Success Stories	34
1.4 Outlook	37
1.5 Online Resources	38
References	42

2 Modeling and Analysis of Gene Regulatory Networks	47
Gilles Bernot, Jean-Paul Comet, Adrien Richard, Madalena Chaves, Jean-Luc Gouzé, and Frédéric Dayan	
2.1 Introduction	47
2.1.1 Biological Systems and Experimental Techniques	48
2.1.2 Mathematical Modeling	49
2.1.3 Chapter Overview.....	50
2.2 Continuous and Hybrid Models of Genetic Regulatory Networks	50
2.2.1 Challenges.....	51
2.2.2 Mathematical Tools	51
2.2.3 Methodological Developments.....	56
2.2.4 Success Stories.....	63
2.3 Discrete Models of GRN	66
2.3.1 Challenges.....	66
2.3.2 Methodological Developments.....	67
2.3.3 Success Story: <i>Pseudomonas aeruginosa</i> and Cystic Fibrosis	75
2.4 Outlook	77
2.5 Online Resources.....	77
References	78

Part II Biomedical Signal and Image Analysis

3 Noninvasive Cardiac Signal Analysis Using Data Decomposition Techniques	83
Vicente Zarzoso, Olivier Meste, Pierre Comon, Decebal Gabriel Latcu, and Nadir Saoudi	
3.1 Preliminaries and Motivation	83
3.1.1 Cardiac Electrophysiology and Genesis of the ECG Signal	83
3.1.2 Two ECG Signal Processing Problems	86
3.1.3 Chapter Overview.....	90
3.2 T-Wave Alternans Detection via Principal Component Analysis	91
3.2.1 Mathematical Modeling of T-Wave Alternans	91
3.2.2 Principal Component Analysis	92
3.2.3 PCA-Based Solution to T-Wave Alternans Detection	95
3.2.4 Success Story: T-Wave Alternans Detection During Angioplasty	97
3.3 Atrial Activity Extraction via Independent Component Analysis	98
3.3.1 Linear Mixture Model	98
3.3.2 PCA Solution to BSS	101
3.3.3 Beyond PCA: ICA	102
3.3.4 Refining ICA for Improved Atrial Signal Extraction	108
3.3.5 Success Stories.....	110

3.4 Conclusion and Outlook	112
3.5 Online Resources.....	114
References	115
4 Deconvolution and Denoising for Confocal Microscopy	117
Praveen Pankajakshan, Gilbert Engler, Laure Blanc-Féraud, and Josiane Zerubia	
4.1 Introduction	117
4.1.1 The World of Microscopy and Beyond	117
4.1.2 Imaging by Fluorescence	118
4.1.3 Bettering the Resolution.....	123
4.1.4 Chapter Overview.....	124
4.2 Development of the Auxiliary Computational Lens.....	126
4.2.1 Confocality Improves Resolving Power	126
4.2.2 Resolution and Contrast Improvement by Deconvolution	136
4.2.3 Implicit Denoising by Regularization.....	141
4.2.4 Success Stories	147
4.3 Outlook	151
4.3.1 Algorithmic Developments.....	151
4.3.2 Search for an Ideal Prior.....	151
4.3.3 Blind Shift-Varying Deconvolution	151
4.4 Online Resources.....	153
References	159
5 Statistical Shape Analysis of Surfaces in Medical Images Applied to the Tetralogy of Fallot Heart.....	165
Kristin McLeod, Tommaso Mansi, Maxime Sermesant, Giacomo Pongiglione, and Xavier Pennec	
5.1 Introduction	165
5.1.1 Repaired Tetralogy of Fallot	166
5.1.2 Chapter Overview.....	168
5.2 Statistical Shape Analysis	168
5.2.1 Shapes, Forms and Deformations	168
5.2.2 From Points to Surfaces: The Formalism of Currents	171
5.2.3 An Algorithm for Surface Registration Using Currents	174
5.2.4 Building an Unbiased Atlas	176
5.3 Shape Analysis of ToF Data	177
5.3.1 The Analysis Pipeline	178
5.3.2 Diagnosis Parameters.....	179
5.3.3 Building an Evolution Model	182
5.4 Conclusion	187
5.5 Online Resources.....	188
References	189

6 From Diffusion MRI to Brain Connectomics	193
Aurobrata Ghosh and Rachid Deriche	
6.1 Introduction	193
6.1.1 The Central Nervous System	194
6.1.2 In Vivo CNS Connectivity	195
6.1.3 Chapter Overview.....	196
6.2 A Brief History of NMR and MRI	197
6.3 Nuclear Magnetic Resonance and Diffusion.....	198
6.3.1 The Hahn Spin Echo Experiment	200
6.3.2 Diffusion	201
6.3.3 The Stejskal-Tanner PGSE Experiment	205
6.3.4 Narrow Gradient Pulse PGSE: q-Space Formalism	207
6.4 From Diffusion MRI to Tissue Microstructure	209
6.4.1 Diffusion Tensor Imaging: The Simplest Model	209
6.4.2 Beyond DTI	213
6.5 Computational Framework for Processing Diffusion MR Images....	216
6.5.1 The Affine Invariant Riemannian Metric for Diffusion Tensors	217
6.5.2 Estimation of DTs in $\mathcal{S}ym_3^+$ Using the Riemannian Metric	218
6.5.3 Segmentation of a Tensor Field	218
6.6 Tractography: Inferring the Connectivity	220
6.6.1 Deterministic Tractography	221
6.6.2 Probabilistic Tractography	223
6.7 Clinical Applications	224
6.8 Conclusion	226
6.9 Online Resources.....	228
References	231

Part III Modeling in Neuroscience

7 Single-Trial Analysis of Bioelectromagnetic Signals: The Quest for Hidden Information.....	237
Maureen Clerc, Théodore Papadopulo, and Christian Bénar	
7.1 Introduction	237
7.1.1 Electric Activity in the Brain.....	237
7.1.2 Measuring Brain Activity	238
7.1.3 Bioelectromagnetic Signal Analysis	239
7.1.4 Chapter Overview.....	240
7.2 Data-Driven Approaches: Non-linear Dimensionality Reduction	241
7.2.1 Principal Components Analysis of a Multitrial Dataset.....	242
7.2.2 Nonlinear Embedding via the Graph Laplacian	242
7.2.3 Application to the Reordering of EEG Times Series.....	245
7.3 Model-Driven Approaches: Matching Pursuit and Its Extensions	247
7.3.1 Matching Pursuit.....	248
7.3.2 A Dictionary Tuned for MEG and EEG	249

7.3.3 Consensus Matching Pursuit	250
7.3.4 Experiments with Real Data.....	251
7.4 Success Stories	252
7.4.1 Co-variations Between EEG and fMRI Signals	253
7.4.2 Distinction Between Latency and Amplitude Effects in Evoked Potentials.....	253
7.4.3 Habituation and Learning Effects	255
7.5 Conclusion	255
7.6 Online Resources.....	255
References	258
8 Spike Train Statistics from Empirical Facts to Theory: The Case of the Retina	261
Bruno Cessac and Adrian G. Palacios	
8.1 Introduction	261
8.1.1 Chapter Overview.....	262
8.2 Unraveling the Neural Code in the Retina via Spike Train Statistics Analysis	262
8.2.1 Retina Structure and Functions	262
8.2.2 Multi-electrodes Array Acquisition.....	266
8.2.3 Encoding a Visual Scene	267
8.2.4 The Ganglion Cells Diversity	268
8.2.5 Population Code	269
8.3 Spike Train Statistics from a Theoretical Perspective	269
8.3.1 Spike Statistics	270
8.3.2 Determining the “Best” Markov Chain to Describe an Experimental Raster	275
8.4 Using Gibbs Distributions to Analysing Spike Trains Statistics	286
8.4.1 Are Ganglion Cells Independent Encoders?.....	287
8.4.2 Weak-Pairwise Correlations Imply Strongly Correlated Network States in a Neural Population	287
8.4.3 The Architecture of Functional Interaction Networks in the Retina	289
8.4.4 Spike Train Analysis in a Neural Network Model	290
8.5 Conclusion	295
8.5.1 Ising or Not Ising?	295
8.5.2 Linear Potentials Versus Combinatorial Explosion	296
8.6 Outlook	296
8.6.1 Gibbs Distributions and the Neural Code.....	297
8.6.2 Experimental Limits	297
8.7 Online Resources.....	298
References	300
Biology, Medicine and Biophysics Index.....	303
Mathematics and Computer Science Index	307
Overall Index	311